Determination of Molar Mass by Vapor Density

One of the properties that helps characterize a substance is its molar mass. If the substance in question is a volatile liquid, a common method to determine its molar mass is to vaporize it and apply the ideal gas law, $PV = nRT$ to the data collected. Because the liquid is *volatile*, it can easily be converted to a vapor. Volatile substances are usually composed of nonpolar molecules. As a result the molecules have primarily London dispersion forces and very little thermal energy is required to overcome these attractive forces since the molecules are relatively small. Therefore, the liquid vaporizes easily and quickly at temperatures less than 100°C. While the substance is in the vapor phase, you can measure its volume, pressure, and temperature. You can then use the ideal gas law to calculate the number of moles of the substance. Finally, you can use the number of moles of the gas to calculate molar mass.

OBJECTIVES

In this experiment, you will

- Evaporate a sample of a liquid substance and measure certain physical properties of the substance as it condenses.
- Determine the molar mass of an unknown liquid.

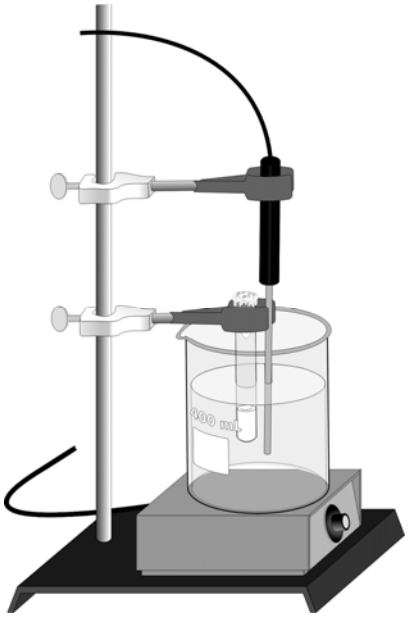

Figure 1

Best results are obtained when the test tube containing the sample is submerged in the water bath to just below the foil cap.

Consider using tall form beakers for your water baths.

MATERIALS

Data Collection Mechanism
Temperature Probe
Gas Pressure Sensor or barometer
ring stand
two utility clamps
aluminum foil
ice
unknown volatile liquid
fume hood
test tube, 13 × 100 mm, and holder
two 400 mL beakers (or larger)
hot plate
analytical balance
needle
tissues or paper towels

PROCEDURE

Before beginning the experiment, make sure that you have a means of measuring the barometric pressure in the room. A conventional barometer or a Gas Pressure Sensor may be used.

1. Obtain and wear goggles. Conduct this experiment in a fume hood or well-ventilated area.

2. Trim a piece of aluminum foil so that it just covers the top of a small, 13 × 100 mm, test tube. Use a needle to make a small hole in the center of the foil. Measure and record the mass of the test tube and foil.

3. Prepare a hot-water bath by warming about 300 mL of tap water in a 400 mL beaker. Keep the beaker on a hot plate once the water is warm. You want it to boil by Step 8.

4. Use a second 400 mL beaker to prepare an ice-water bath.

5. Set up the data collection system.
   a. Connect a Temperature Probe to the interface.
   b. Start the data collection program. Be sure the program shows the correct readings for the probe.
   c. There is no need to store and graph the data for this experiment.

6. Obtain a liquid sample of an unknown volatile compound. Pour about 0.5 mL of the liquid into the test tube and quickly cover the test tube with the aluminum foil. Use your fingernail to make an air-tight seal with the foil just under the lip of the test tube. Place the test tube in the hot water bath. Make sure that the foil is above the water level, but submerge your test tube as far as possible without making contact with the bottom of the beaker (see Figure 1).

7. Immerse the Temperature Probe in the hot-water bath (see Figure 1). Do not allow the tip of the probe to touch the beaker.

8. Heat the hot-water bath to boiling and maintain the boiling as your sample of liquid vaporizes. Note that some of your sample will escape the test tube through the needle hole in the foil. This process also serves to flush the air out of the test tube.

9. Keep the test tube in the boiling-water bath for at least three minutes *after* all of the liquid in the test tube has vaporized. Watch the temperature readings and record the temperature of the boiling water bath, which will be used in the ideal gas law calculations.

10. Use a test-tube holder to *quickly* transfer the test tube to the ice water bath. Cool the test tube for about one minute, then remove it and dry it completely. Measure and record the mass of the test tube and the aluminum foil top.

11. Record the room's barometric pressure.

12. Rinse out the test tube and fill it to the top with tap water. Cover the test tube with the aluminum foil. Measure and record the mass of the test tube, water, and foil.

DATA TABLE

	Trial 1	Trial 2
Mass of test tube and foil cover (g)		
Temperature of hot water bath (ºC)		
Mass of test tube and foil and gas sample (g)		
Barometric pressure (atm)		
Mass of test tube and foil and water (g)		

PRE-LAB QUESTIONS

1. What is the difference between a vapor and a gas?

2. A student performs an experiment designed to determine the molar mass of a sample of an unknown volatile liquid. The following data was collected:

	Trial 1
Mass of test tube and foil cover (g)	7.5228 g
Temperature of water bath (ºC)	99°C
Mass of test tube and foil and condensed gas (g)	7.5387 g
Barometric pressure (atm)	0.987 atm
Mass of test tube and foil and water (g)	16.1228 g

(a) Determine the mass of the condensed unknown.

(b) Assuming the density of water to be 1.00 g/mL, determine the total volume of the test tube.

(c) Starting with the ideal gas law, substitute the fact that *n* is equal to grams/molar mass and derive an expression for calculating the experimental molar mass of the student's volatile liquid sample.

(d) Calculate the molar mass for this student's sample.

(e) Calculate the percent error for this student's experimental determination of the molar mass assuming the unknown liquid was methyl alcohol (CH_3OH).

POST-LAB QUESTIONS AND DATA ANALYSIS

1. Determine the mass of the condensed unknown.

2. Use the mass and density of the water in the test tube from Step 12 of the procedure to calculate the volume of the test tube.

3. Use the expression you derived for Pre-Lab Question # 2 part (c) along with the data collected to calculate the molar mass of your unknown compound.

4. Use your experimentally determined molar mass and reference material to identify the unknown volatile liquid you tested.

5. A student failed to vaporize the entire sample prior to placing the test tube in the ice bath. How did this error affect the calculated molar mass? Justify your answer using calculations.

6. A different student failed to dry the outside of the test tube prior to massing it in Step 12. How did this error affect the calculated molar mass? Justify your answer using calculations.

7. How would your calculated molar mass have been affected if you had used twice the initial amount of the unknown compound?